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INTERIM REPORT

on the

FREQUENCY AND MAGNITUDE OF FLOODS

in

EASTERN MONTANA

By Fred C. Boner

Prepared in cooperation

with the

Montana State Highway Commission

and the

U.S. Department of Commerce, Bureau of Public Roads

U.S. Geological Survey
408 Federal Building
Helena, Montana
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INTRODUCTION

An open-file report, "Floods in Eastern Montana, Magnitude and Frequency" by V. K. Berwick, was released in May 1958 by the U.S. Geological Survey in cooperation with the Montana State Highway Commission. The report presented a method for determining the magnitude and frequency of probable floods, applicable to any drainage area from 35 to 3,000 square miles, in most of eastern Montana. A composite frequency curve that expressed the relation of the mean annual flood to floods having a recurrence interval from 1.05 to 20 years was defined. The composite curve was based on the combined frequency curves for 16 stations having 5 or more years of record. An equation was derived expressing the relation between mean annual flood, drainage area, and mean elevation of the basin.

The small-area peak-flow highway program in Montana began in the summer of 1955. The program is financed under the provisions of a cooperative agreement between the Montana State Highway Commission and the Geological Survey, which provides for full reimbursement of appropriate costs by the Commission through its Planning Survey. The State is in turn reimbursed from U.S. Bureau of Public Roads funds to the extent of about three-fourths of the project costs.

In addition to the 1958 flood-frequency report and annual progress reports, the two agencies agreed that all the data would be analyzed at the end of 6 years, including the data collected for the original group of about 40 crest-stage gages in eastern Montana. The object of this interim report is to present the results of that analysis. This report revises the open-file report of May 1958 and covers the additional period 1956-61. It is also expanded to cover drainage areas ranging from less than 1 square mile to about 3,200 square miles, using the data collected under the highway program.

DATA USED

Approximately 40 crest-stage gages have been operated in eastern Montana since the summer of 1955. These gages record peak stages but do not record peak discharges. Twenty-five of these stations have curves defined that relate stage to discharge. Data obtained at the other fifteen stations could not be used at this time. Several other station records were not used because the mean annual flood, determined on basis of the very short period of record, was not adequately defined. Adequate peak-flow records obtained at nineteen crest-stage gage stations were used in this analysis.

The open-file report of May 1958 used peak-flow records at 16 gaging stations for which complete daily records are available. Records for these stations, with the exception of Little Beaver Creek near Marmarth, N. Dak., and those for six

additional stations, were used. The period of record covered by the original report was 1938-56. This report covers the period 1938-61.

A total of 40 stations, 21 long-term stations and 19 crest-stage stations, were used in this analysis. The stations used in the study are listed in table 1.

FLOOD-FREQUENCY RELATIONS

Methods of Analysis

The techniques used in this report to analyze the frequency and magnitude of floods have been developed by engineers of the Water Resources Division of the Geological Survey. The basic data are the annual flood series which are lists of only one flood, the annual maximum, during each water year. For recurrence intervals greater than 10 years, the annual flood series gives almost identical results as those from the partial-duration series which includes all peaks above an arbitrary base.

The flood-frequency relation at one gaging station represents a sample for that point only for a relatively short period of time. The combination of several homogeneous records in a region will reduce the possibility of chance variation in the floods of record and will provide a means of estimating flood frequencies on ungaged areas.

Only three of the crest-stage gage stations failed to meet the statistical homogeneity test, possibly because of poor definition of the station frequency curve. However, these 3 records and the other 37 records were considered homogeneous.

Composite Frequency Curves

The long-term stations were grouped together to compute the average flood ratios for each recurrence interval. This composite flood-frequency curve is shown in figure 1 and is for the base period 1938-61.

A comparison was made between the long-term stations and crest-stage stations for the common 6-year period, 1956-61. Composite flood-frequency curves for the two groups are shown in figure 2 along with the composite flood-frequency curve for the long-term stations for the longer period, 1938-61.

The curves for the shorter period compare quite favorably with those for the longer period although there is some divergence to the left at the upper end. Experience has demonstrated that the upper end of short-period curves generally move to the right with greater length of record. Therefore, the composite frequency curve for the long-term, larger-area stations, shown in figure 1, is assumed to be applicable to the streams having shorter records on smaller drainage areas.

DERIVATION OF MEAN ANNUAL FLOOD

Some of the factors which may influence the mean annual flood at a given point are size of drainage area, channel storage, shape of the basin, direction of storm travel, artificial or natural storage, land slope, elevation, underlying geology, soil and its vegetal cover. Many of these factors are, of course, difficult to evaluate and cannot be used in a cor-

relation. A correlation study was made using some of the more significant basin characteristics that could be adequately measured and that might affect the mean annual flood.

The drainage area was the first characteristic considered and was found to correlate fairly well with the mean annual flood. Substantial error would result, however, from estimating the mean annual flood from drainage area alone.

In the open-file report of May 1958, the mean elevation was found to have correlative value. Further investigation has revealed a more easily determined basin elevation factor, which also has correlative value. This is the average of the elevations at the two-tenths and eight-tenths points of the meander length of the main stream upstream from the gage. The meander length of each stream above the gage site was determined by use of a map measure. Elevations and meander lengths were obtained from Army Map Service topographic maps of the western United States having a scale 1:250,000.

The third factor which improves the multiple correlation is the meander length of the main stream course. This factor made only minor improvement in the multiple correlation, but the meander length had previously been determined and it was included in the formula.

The residuals from the multiple correlation studies had a tendency to plot in groups according to geographical location, indicating that location is a major contributing factor

to the size of the residuals. To account for the geographical effect, a geographical factor was introduced into the formula for determining the mean annual flood. The part of eastern Montana being considered in this analysis was divided into three geographical subregions, as shown in figure 3.

The final multiple correlation was made with mean annual flood as the dependent variable and with drainage area, elevation, meander length and geographical factor as the independent variables. The factors used for the different basin characteristics are tabulated in table 1.

FORMULA

The formula for mean annual flood as derived from the 40 gaging stations by multiple correlation is:

$$Q_{MAF} = 278{,}000 \; A^{.382} \; E^{-1.255} \; L^{.423} \; G$$

where A = drainage area, in square miles

E = average of elevations at 2/10 and 8/10 meander length of main stream course, in feet

L = meander length of the main stream course, in miles, measured on Army Map Service topographic maps having a scale 1:250,000

G = geographical factor, in units

The standard error of estimate ranges between +37 percent and -27 percent of the mean. Although this is nearly twice the standard error of estimate for the formula used in the previous report, the composite frequency curve can be used with more confidence because additional data is available. Part of the standard error of estimate is attributed to errors

in the frequency curves for individual stations, particularly those with short-term records.

APPLICATION OF REGIONAL FLOOD-FREQUENCY CURVE

The magnitude of a flood of a selected recurrence interval can be determined by the following procedure:

1. Determine the size of drainage area in square miles above the selected site.

2. Measure the meander length of the main stream course in miles above the selected site using Army Map Service topographic maps, scale 1:250,000.

3. Find the elevation in feet at 2/10 and 8/10 meander length of the main stream course and average the two figures.

4. From figure 3 determine the geographical area in which the site is located and select the appropriate geographical factor.

5. Compute the mean annual flood by inserting the values of drainage area, elevation, meander length, and geographical factor into the formula:

$$Q_{MAF} = 278{,}000 \; A^{.382} \; E^{-1.255} \; L^{.423} \; G$$

6. Determine the ratio to the mean annual flood for the selected recurrence interval from figure 1.

7. Multiply the ratio to the mean annual flood (step 6) by the mean annual flood (step 5) to obtain the desired flood magnitude.

A complete frequency curve for a site can be drawn from

points computed by repeating steps 6 and 7 for several selected recurrence intervals.

For ease of application, the formula can be given the general form: $Q_{MAF} = K_A\ K_E\ K_L\ G$, where the K values are obtained from the appropriate diagrams in figures 4, 5 and 6. An example of the use of the K diagrams is shown below:

Sample solution:

From a topographic map the drainage area is found to be 24 square miles. The meander length of the main stream course is measured from an Army Map Service topographic map (scale, 1:250,000) and found to be 11 miles. The elevations at 2/10 and 8/10 meander length are 3,410 and 4,350 ft, msl. The drainage basin is located in southeastern Montana where the geographical factor is 3.05, from figure 3.

$A = 24$ square miles $\qquad K_A = 3.3$ from figure 4

$E = \frac{3,410 + 4,350}{2} = 3,880 \qquad K_E = 8.7$ from figure 5

$L = 11$ miles $\qquad K_L = 2.8$ from figure 6

$$Q_{MAF} = K_A\ K_E\ K_L\ G = (3.3)(8.7)(2.8)(3.05) = 245 \text{ cfs}$$

For a recurrence interval of 25 years, from figure 1,

$$Q_{25} = (3.6)(245) = 882 \text{ cfs}$$

LIMITATIONS

The results given herein for computing the magnitude and frequency of floods should be considered provisional and subject to substantial error. The main source of error might be in the assumption that the composite frequency curve for the long-term stations is applicable for all sizes of drainage areas. As more crest-stage stations become rated and the length of record increased, these data will be included to add confidence to the present study and will undoubtedly lead to revisions and improvement.

The reader is warned that the formula and curve given herein should not be used for streams outside the study area, that the elevation factor be limited to areas below 6,000 feet above mean sea level, that the drainage areas are between 0.5 and 3,200 square miles in size, and that the composite flood-frequency curve should not be extended.

Table 1.—Factors used in the multiple correlation of mean annual flood with basin characteristics

Order No.	Perm. Sta. No.	Station	Mean Annual Flood Q_{MAF}	Drain. Area A	Ave. Elev. E	Meander Length L	Geogr. Factor G
1	1155.	N.F. Musselshell River near Delpine	102	31.4	6,150	12	2.02
2	1206.	Antelope Creek tributary near Harlowton	5.2	.47	5,380	1.3	2.02
3	1209.	Antelope Creek at Harlowton	330	88.7	4,830	26	2.02
4	1220.	American Fork below Lebo Creek, near Harlowton	400	166	5,400	38	2.02
5	1277.	Box Elder Creek tributary near Winnett	167	16.2	2,880	6.0	2.02
6	1287.	Gorman Coulee near Cat Creek	77	2.32	2,840	2.7	2.02
7	1288.	Gorman Coulee tributary near Cat Creek	36	.81	2,860	1.8	2.02
8	1310.	Dry Creek near Van Norman	5,300	2,554	2,720	68	2.02
9	1545.	Peoples Creek near Dodson	1,030	670	3,060	60	1.00
10	1553.	Disjardin Coulee near Malta	35	3.42	2,460	3.3	1.00
11	1554.	S.F. Taylor Creek near Malta	52	5.08	2,510	5.0	1.00
12	1560.	Whitewater Creek near international boundary	530	458	2,780	32	1.00
13	1685.	Rock Creek at international boundary	925	241	2,820	30	2.02
14	1690.	Horse Creek at international boundary	420	73.5	2,760	18	2.02
15	1700.	McEachern Creek at international boundary	850	182	2,740	18	2.02
16	1765.	Wolf Creek near Wolf Point	1,150	251	2,400	31	2.02
17	1770.5	E.F. Duck Creek near Brockway	160	12.4	2,820	8.3	2.02
18	1771.	Duck Creek near Brockway	560	54.0	2,800	14	2.02
19	1773.	Redwater Creek tributary near Brockway	18	.29	2,630	.6	2.02
20	1773.5	S.F. Dry Ash Creek near Circle	56	5.74	2,820	4.4	2.02
21	1775.	Redwater Creek at Circle	1,550	547	2,680	37	2.02
22	1780.	M.F. Poplar River at international boundary	880	362	2,860	41	2.02
23	1785.	E.F. Poplar River at international boundary	915	534	2,520	23	2.02
24	1810.	Poplar River near Poplar	4,600	3,174	2,460	115	2.02
25	1825.	Big Muddy Creek at Daleview	1,810	279	2,360	28	3.05

Table 1.--Factors used in the multiple correlation of mean annual flood with basin characteristics--Continued

Order No.	Perm. Sta. No.	Station	Mean Annual Flood Q_{MAF}	Drain. Area A	Ave. Elev. E	Meander Length L	Geogr. Factor G
26	1831.	Box Elder Creek near Plentywood	125	9.40	2,300	4.5	3.05
27	1832.	Box Elder Creek at damsite, near Plentywood	595	19.9	2,240	7.3	3.05
28	1834.	Spring Creek at Highway 16, near Plentywood	460	16.9	2,230	8.0	3.05
29	2110.	Red Lodge Creek above Cooney Reservoir, near Boyd	440	143	5,200	26	2.02
30	2115.	Willow Creek near Boyd	194	53.3	5,080	22	2.02
31	2163.	West Buckeye Creek near Billings	67	1.54	3,680	3.0	2.02
32	2165.	Pryor Creek near Billings	640	435	4,140	40	2.02
33	2875.	Soap Creek near St. Xavier	360	98.3	4,260	18	2.02
34	2900.	Pass Creek near Wyola	395	111	5,000	17	2.02
35	2935.	Little Bighorn River near Crow Agency	1,720	1,181	4,480	69	2.02
36	3082.	Basin Creek tributary near Volborg	9.0	.14	3,020	.6	2.02
37	3247.	Sand Creek near Broadus	69	10.6	3,220	5.0	2.02
38	3255.	Little Powder River near Broadus	1,410	1,974	3,640	90	2.02
39	3340.	Little Missouri River near Alzada	1,830	904	3,750	58	3.05
40	3365.	Beaver Creek at Wibaux	1,590	351	2,920	44	3.05

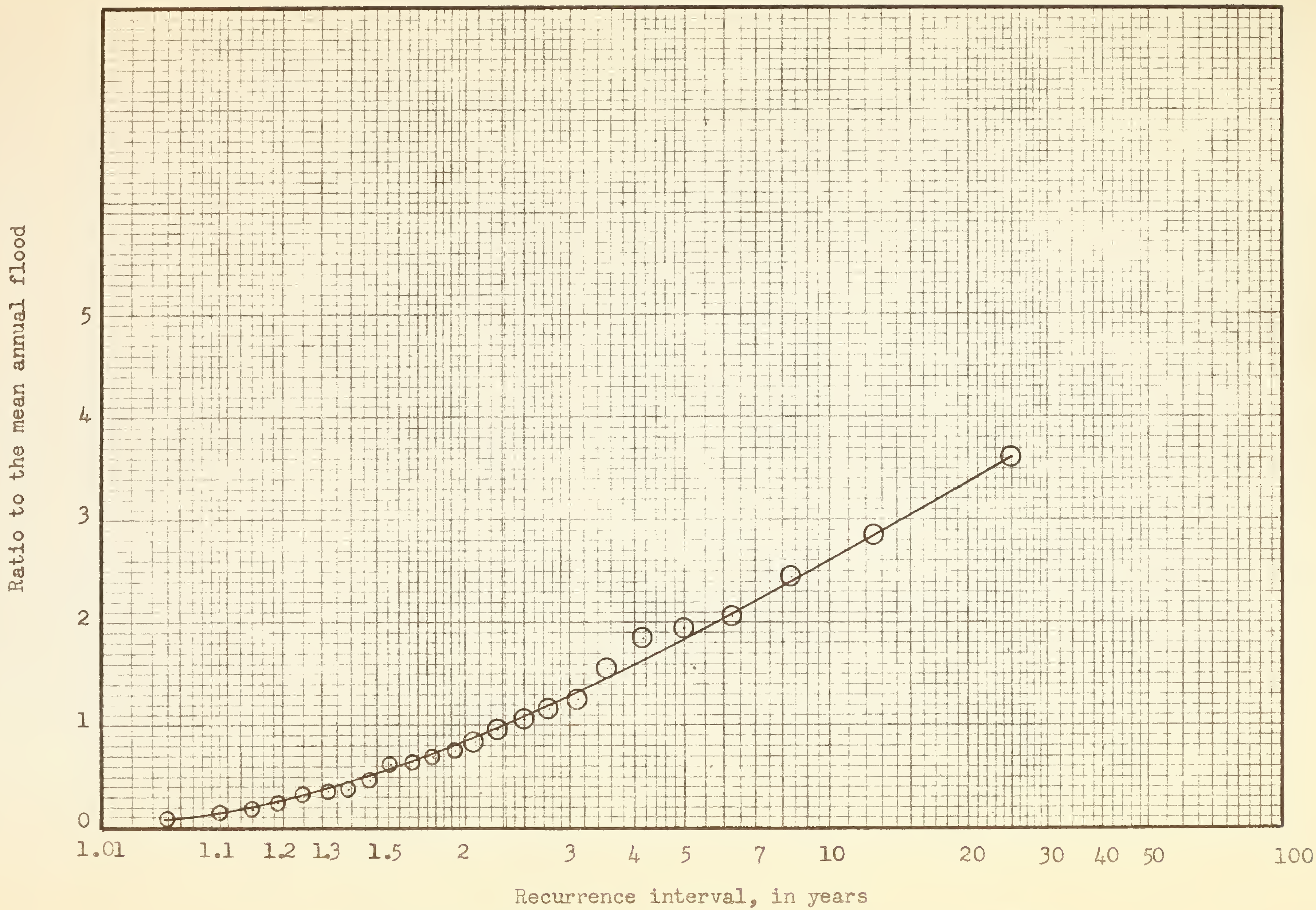


Figure 1.—Composite flood-frequency curve for eastern Montana

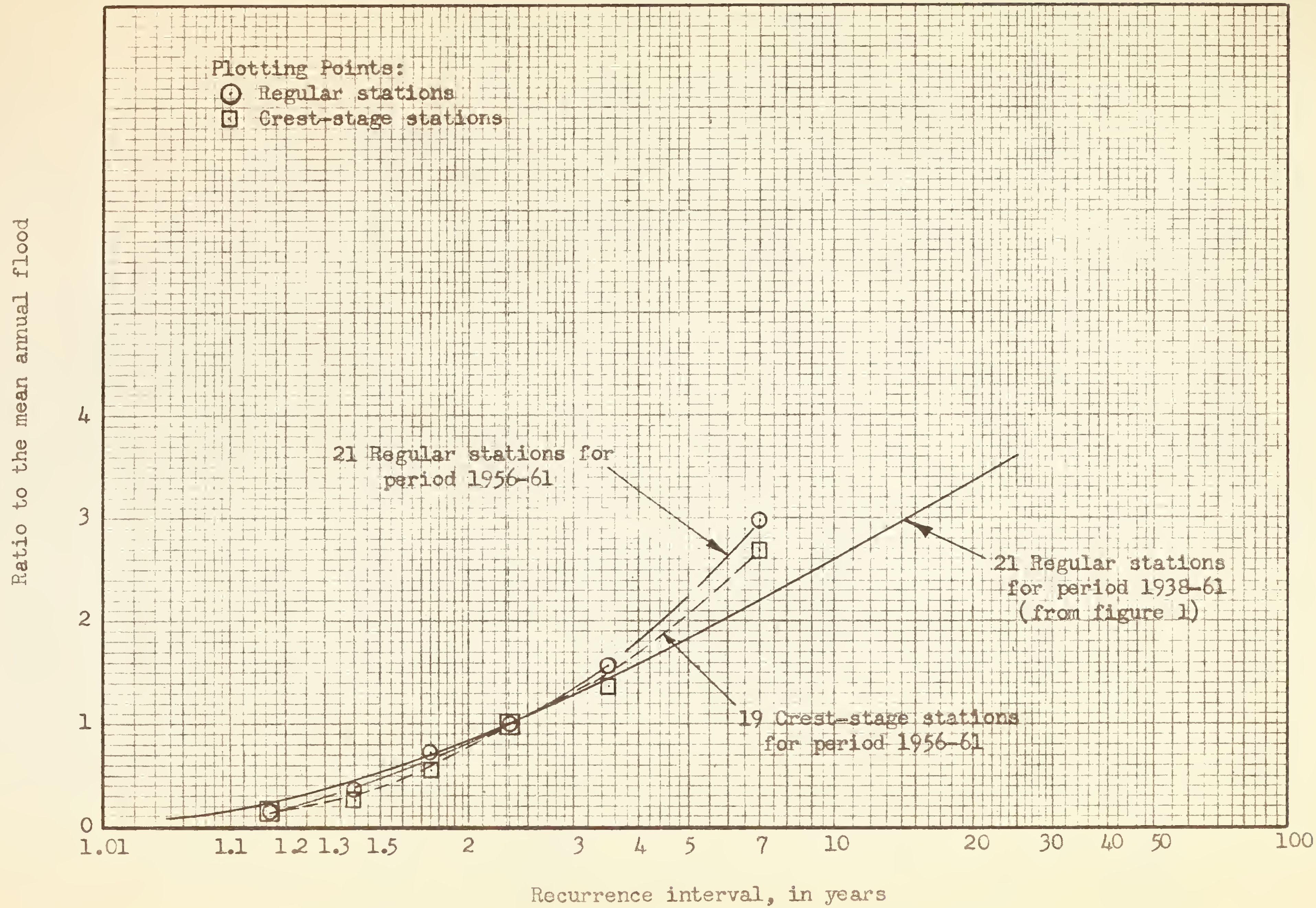


Figure 2.—Comparison of composite flood-frequency curves.

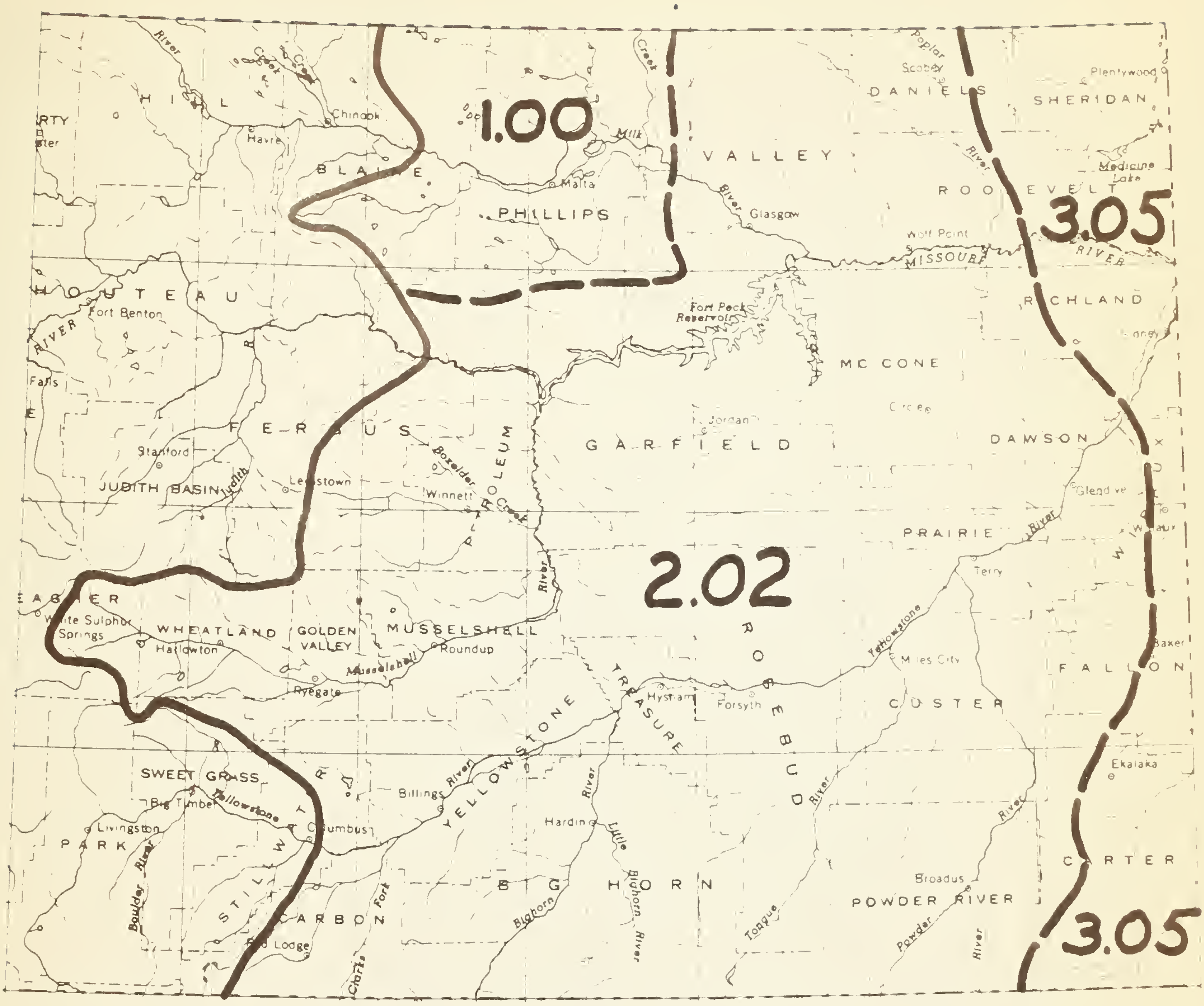


Figure 3.--Areas to which geographical factors apply in eastern Montana.

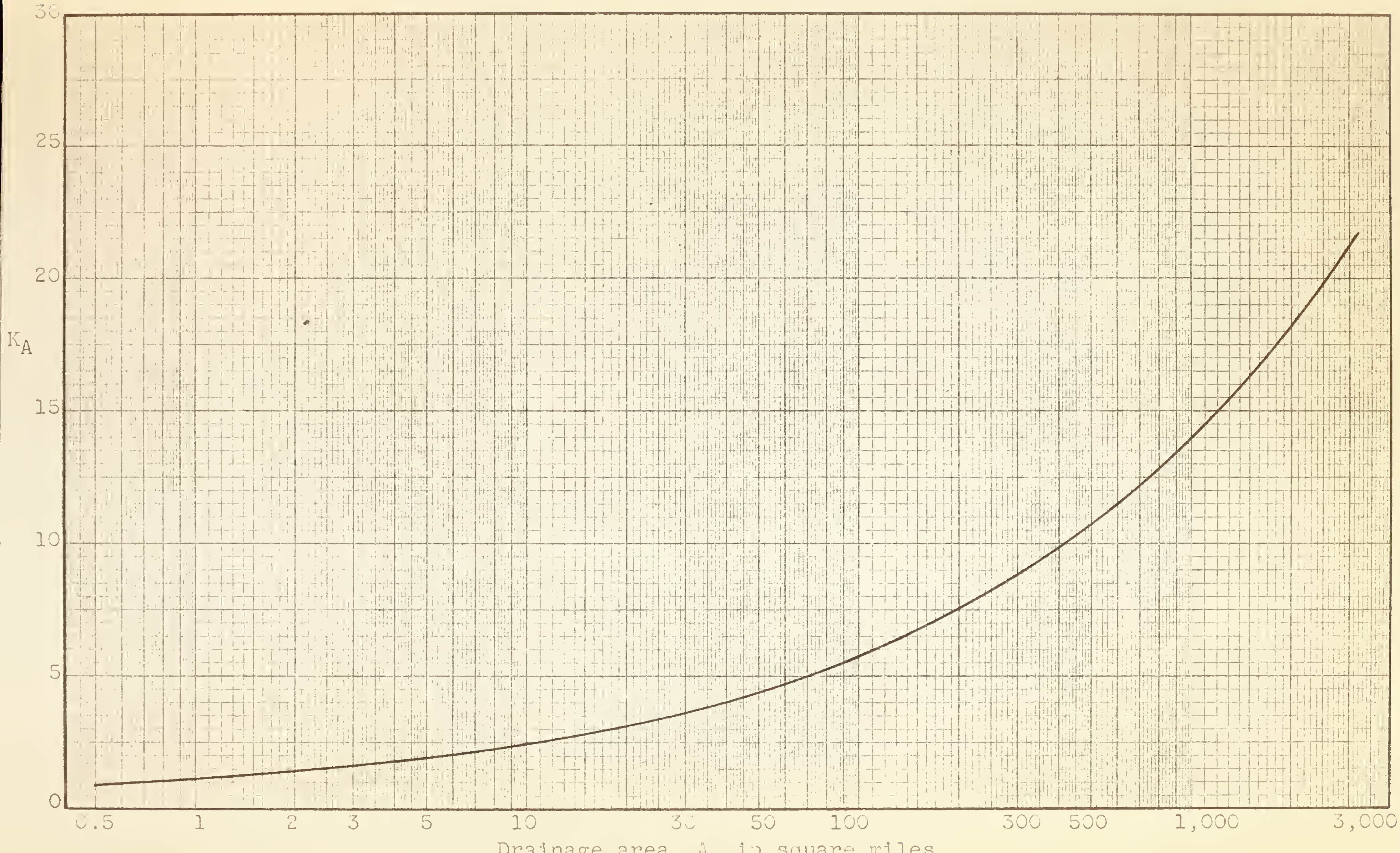


Figure 4.--Variation of K_A with drainage area.

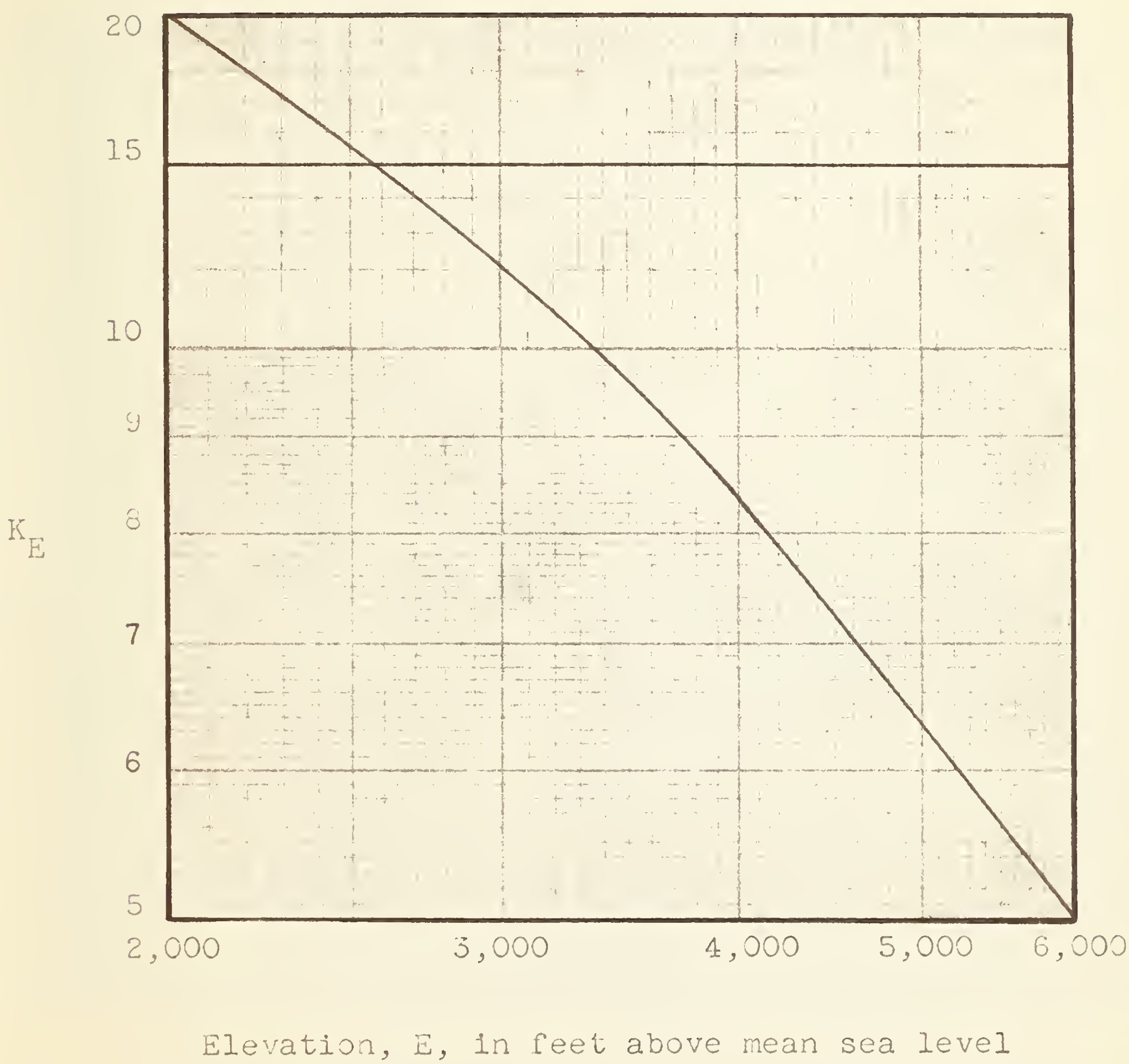
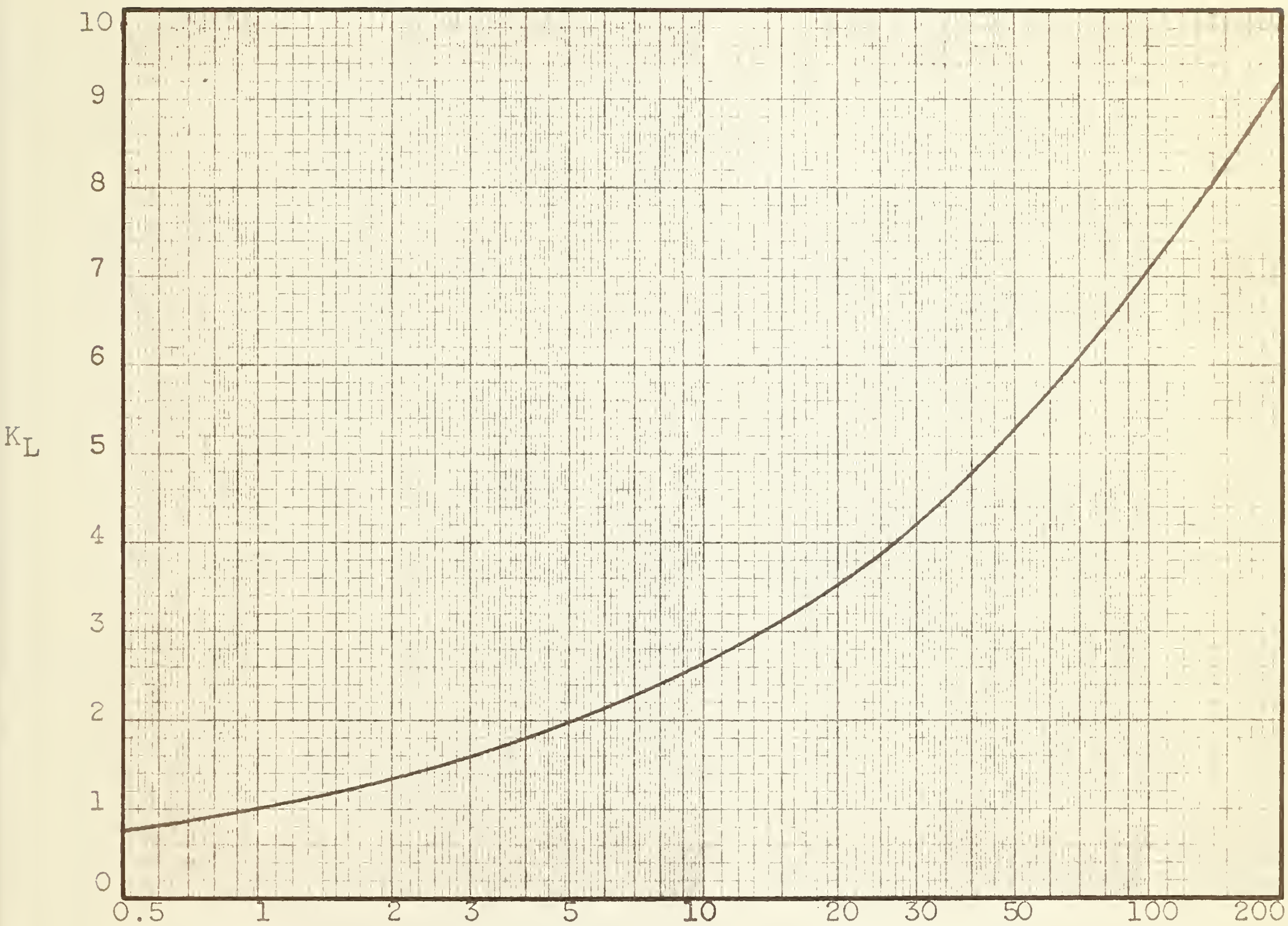


Figure 5.--Variation of K_E with elevation



Meander length of main stream course, L, in miles

Figure 6.--Variation of K_L with meander length of main stream course.